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Remote Hands-On Experience for Students in Undergraduate Computer and Electrical Engineering

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ABSTRACT

The focus of this research was to analyze current methods for online education for electrical and computer engineering undergraduate programs. From this research, an online model for virtual labs in undergraduate engineering is introduced. Experiential learning was exhibited by students through the hands-on experience with lab equipment combined with user feedback. Software used in this research to simulate traditional lab equipment affords institutions the opportunity to provide instructive methods to remote students who are unable to complete on-campus curricula. The devices used to remotely complete the virtual labs facilitated high-value lab practices and skills comparable to those presented in an on-campus lab. As examined during this research, the opportunity to operate virtual devices with the simulation software delivered an extensive laboratory experience with the capability to create a teaching method for engineering concepts. Data from the students' feedback on the simulated, interactive learning is presented in this paper.

Keywords - hands-on, engineering, virtual devices, online labs, assessment, student research

1. INTRODUCTION

The primary hurdle to a 100% online bachelor engineering degree program is the hands-on-laboratory experience required of engineering students before graduation. A four-year undergraduate curriculum for a Bachelor of Science in Electrical Engineering requires students' participation in laboratories [1]. The Accreditation Board for Engineering and Technology (ABET) Criterion 3 1-7 identifies learning outcomes in individual courses with associated labs [1], [2]. Criterion 3-6 states that students must "develop and conduct appropriate experimentations" as well as "analyze and interpret data" in the form of physical demonstrations of project labs, lab finals, or lab reports that can be used to institute the hands-on experience requirement [1-5]. The application of theoretical concepts and adherence to engineering laws during laboratory experiments are essential fundamentals key to any undergraduate engineering program, establishing laboratories as critical components in both learning and assessment [1]. These labs introduce students to electrical components (ex. resistors, capacitors, and inductors), equipment (ex. digital multimeters, DC power supply, oscilloscopes, and function generators), reading schematics and constructing circuitry. Hands-on laboratory experiences also empower students to form observation, testing, and define conclusion skills; thereby, confirming the necessity for hands-on experience. Learning through trial and error is an important aspect of testing experiments and is one of the nine objectives for the engineering education laboratory as defined by ABET.

2. WHY ONLINE DEGREES?

For institutions, momentarily not considering cost, the process is to merely offer the class and set the schedule; however, for students with constraints to physical access to laboratory facilities, this feat could prove challenging or impossible. Online-delivered coursework opens the possibility of obtaining a college degree for students who otherwise would not have the opportunity to visit a full immersion school [1]. This could also include the underserved in electrical and computer engineering programs, which was the initial goal of Phillip *et al* [6] for implementing the online program. The characteristics of the online students enrolled in online delivery (age, professional experience, veteran/military status, etc.) differ from those of the students enrolled in face-to-face courses [6].

[1]We would like to thank to Drs. Frances C. Dancer and Jacqueline M. Jackson for their comprehensive and detailed peer-editing of this document. Their suggestions truly enhanced the quality and impact of this document.

3. ONLINE EDUCATION

Several areas of study are offered through online programs. Due to some specifics within the area of study, offering a program exclusively online is not an option. In these cases, schools may offer hybrid degree options that combine distance learning and campus-based instruction [7]. Topics that can be studied in fully online and/or hybrid programs include Business, Teacher Education, History, English, Computer science, Accounting, Fine art, Sport Management, and Urban and Regional Planning [7]. As technology advanced, more disciplines delved into the arena of online education. Students can now earn online degrees from any discipline, most importantly electrical and computer engineering. Researchers in [1], [5], [6], and [7] explored the various virtual labs that have been developed over the years in different disciplines like Computer Science, Electrical Engineering, Civil Engineering, Chemical Science, Robotics, and others [8]. Computer-based distance education has been growing enormously in recent years due to advances in key technologies that include telecommunications, computer technology, graphical user interfaces, and the internet [9]. Distance education materials can be presented either synchronously, creating the illusion of a classroom on the computer, or asynchronously, allowing the students access on demand [9]. Synchronous courses are typically presented with webcam and chat room technology. Whereas asynchronous courses are presented via e-mail and blogs/discussion boards. The asynchronous method allows the students to access stored educational material on demand. In asynchronous systems, students follow their own pace and may access the course materials independently of other students and at different times [9].

4. COMPONENTS OF AN ONLINE VIRTUAL LAB MODEL

Figure 1 presents the architecture for developing an online education model for electrical and computer engineering programs with virtual labs. In Figure 1, ***Section 1*** describes developing labs applicable to the software, for example, it addresses differences in the software compared to traditional lab equipment. A sample lab completed with the software is provided in the *Virtual Lab vs Traditional Lab* section. In ***Section 2,*** the labs are offered online by the institution through a learning management system, learning management systems such as Blackboard or Canvas. ***Section 3a and 3b*** students enroll in an online lab course and purchase virtual devices. Another option for the cost of the virtual devices is to include the expense in the student's tuition. The cost of virtual devices is covered in the *Proposed Virtual Lab and Its Components* section. ***Section 4*** the students access the labs through the learning management system provided by the institution. Finally, in ***Sections 5 and 6*** the students are given instructions to download the software and setup the hardware. After the students download the software and setup the hardware, they have the option to complete the labs wherever they choose. An example of the hardware setup is demonstrated in the *Virtual Lab Vs Traditional Lab* section.

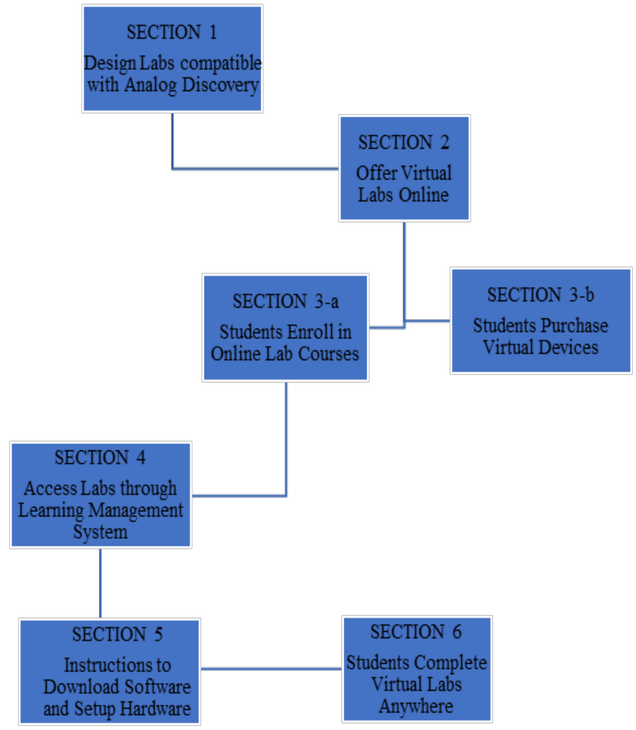

Figure 1. Components of an Online Virtual Lab Model

5. PROPOSED VIRTUAL LAB AND ITS COMPONENTS

Learning through trial and error is an important aspect of testing experiments. Learning from failure is one of the nine objectives for the engineering education laboratory as defined by ABET [10-11]. As demonstrated in this paper, the opportunities for students to purchase virtual device equipment and part kits to use with the simulation software satisfy the hands-on experience requirement. In [2], [5], and [12], the utilization of the parts kits for the student's use at home was successful in achieving the hands-on experience aspect. The proposed solution replaces costly traditional lab equipment and students can conduct these labs anywhere. Analog Discovery was used to create the virtual laboratory in this paper.

There is a 2 X 15 Fly-Wire device used to connect a circuit to the Analog Discovery software. Table 1 shows the wire (color), the connection, and the traditional instrument it simulates.

Table 1. Breakdown of Analog Discovery Paired with 2 X 15 Fly-Wire

Wire	Connection	Instrumentation
Orange & Orange/ White	Channel 1 Positive & Negative	Oscilloscope
Blue & Blue/White	Channel 2 Positive & Negative	Oscilloscope
Black	Ground	
Red & White	+5 AND -5V	Power Supply
Yellow & Yellow/ White	Waveform Generator 1 And 2	Waveform Generator
Gray & Gray/White	Trigger In	Trigger On Oscilloscope
Pink, Green, Purple & Brown	Digital I/O Signals	Logic Analyzer
Pink, Green, Purple & Brown-With White	Digital I/O Signals	Logic Analyzer

6. ANALYSIS OF VIRTUAL DEVICES AND APPLICABLE SOFTWARE

It is important to visually expose concepts to students participating in engineering courses in a real system format for students to grasp an understanding. They must explore fundamental topics used in engineering systems, while working in teams, and apply them in practical designs quickly and effectively [6], [9], [13].

*NI ELVIS III i*s a modular engineering educational laboratory device developed specifically for academia [13]. With its hands-on approach, educators can help students learn practical, experimental engineering skills [13]. The NI ELVIS includes the following: an Oscilloscope*,* Digital Multimeter*,* Function generator*,* Variable power supply*, and* Bode analyzer. To use the detachable protoboard –Connect the NI ELVIS to a PC using a USB cable. *Digilent's Analog Discovery 2* is a USB oscilloscope and multi-function instrument that allows users to measure, visualize, generate, record, and control mixed-signal circuits of all kinds [14]. Analog Discovery 2 is small enough to fit in a pocket but powerful enough to replace a stack of lab equipment, providing engineering students, hobbyists, and electronics enthusiasts the freedom to work with analog and digital circuits in virtually any environment, in or out of the lab [14]. The analog and digital inputs and outputs can be connected to a circuit using simple wire probes. Driven by the free WaveForms 2015 (Mac, Linux, and Windows compatible) software, Analog Discovery 2 can be configured to work as any one of several traditional instruments [14]. The ADALM1000 Active Learning Module is an affordable USB-powered data acquisition module designed to introduce the fundamentals of electrical engineering created by Analog Devices. The ADALM1000 is designed to develop a solid science, technology, or engineering foundation for the targeted audience. This tool illustrates the relationships between current, voltage, and impedance (resistance, inductance, and capacitance) to the user [15]. Pixel pulses 2 provides an innovative graphical user interface (GUI) that minimizes the learning curve and enables students to learn faster, work smarter, and explore more [15].

WaveForms is a powerful multi-instrument software application that seamlessly connects to a USB portable oscilloscope, logic analyzer, and function generator products such as both versions of the Analog Discovery, the Digital Discovery, and the Electronics Explorer Board, with full Windows, Mac OS X, and Linux support [16]. This software, coupled with hardware instrumentation, brings a powerful suite of instruments to enable analog and digital design on your personal computer [16]. Designed with a clean, easy-to-use graphical interface for each instrument, WaveForms makes it easy to acquire, visualize, store, analyze, produce, and reuse analog and digital signals [16]. *LabVIEW* offers a graphical programming approach to help visualize every aspect of the application, including hardware configuration, measurement data, and debugging [17]. This visualization makes it simple to integrate measurement hardware from any vendor, represent complex logic on the diagram, develop data analysis algorithms, and design custom engineering user interfaces [17].

Scopy is a multi-functional software toolset with strong capabilities for signal analysis provided by Analog Devices [15]. It contains the following instruments: Oscilloscope, Spectrum Analyzer, Network Analyzer, Signal Generator, Logic Analyzer, Pattern Generator, Digital IO, Voltmeter, and a Power Supply. Both Scopy and Waveforms are free. The Scopy software used with the ADALM hardware is free to download. Waveforms software is downloadable for free from the Digilent's website. LabVIEW Base starts at $399.00 yearly; prices increase with the different editions LabVIEW Full-$3149.00 and LabVIEW Professional at $5249.00. Table 2 provides an overview of the cost of these devices and their applicable software. Table 3 provides an overview of the cost a student could expect to pay for virtual devices in an online electrical and computer engineering program.

Table 2. Virtual Equipment (and applicable software application) Summarized

Virtual Equipment	Equipment Cost	Software	Software Cost
NELVIS	$2897.00 (one-time expense)	LabVIEW	$399.99 annual
Analog Discovery 2	$319.00 (one-time expense)	Waveforms	Free
ADALM1000	$146.00 (one-time expense) plus $44.95 for the parts kit	Scopy	Free
TCLAB	$35.00	Python MATLAB Simulink	Free $2,150/$860 $3,250/$1300
Breadboard Power Supply	$7.59	N/A	N/A
Basys MX3 trainer board	$99.00	Waveforms	Free (used with Analog Discovery)

Table 3. Virtual Device Cost to Students for Entirety of Program

Virtual Device Purchases for Students	1st YR	2nd YR	3rd YR	4th YR	Total
Analog Discovery 2	$319				$319
Temperature Control Lab		$35			$35
Basys MX3 trainer board w/ $5.00 USB cable			$99/$103		$99
Breadboard Power Supply	$8				
Digital Multimeter	$25				
Total for the Year	$327	$35	$103		**$489**

7. VIRTUAL LAB VS TRADITIONAL LAB

The primary hurdle to a 100% online bachelor engineering degree program is the hands-on-laboratory experience required of engineering students before graduation. It was important to complete labs utilizing and illustrating important engineering laws and theorems to demonstrate students would still receive this vital information.

Topics for an Electronics course include diode, BJT, and FET circuits, covering frequency response, biasing, current sources and mirrors, small-signed analysis, and design of operational amplifiers. The sample lab demonstrated in this paper was Diode Characteristics. The objective was to examine and plot the forward characteristics curve of a p-n junction diode and become familiar with the characteristics of both the p-n junction diode and the light emitting diode (LED). The LED objectives were not covered in this paper.

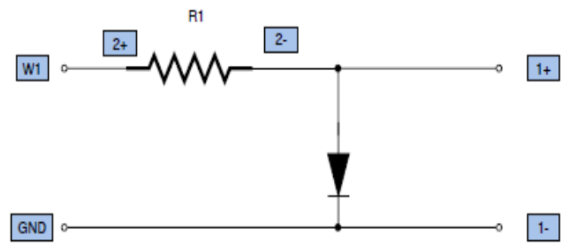

Figure 3. Diode Bias Schematic Constructed with Analog Discovery

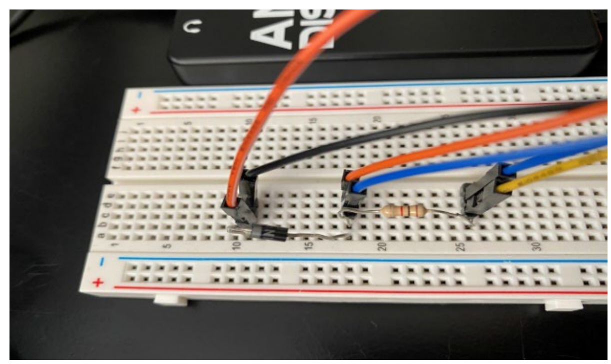

Figure 4. Diode Bias Circuit Constructed with Analog Discovery

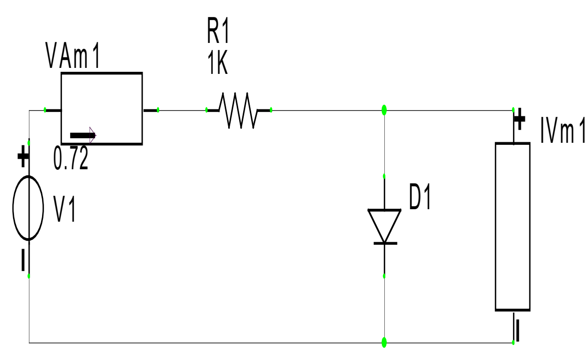

Figure 5. Diode Bias Schematic Traditional Construction

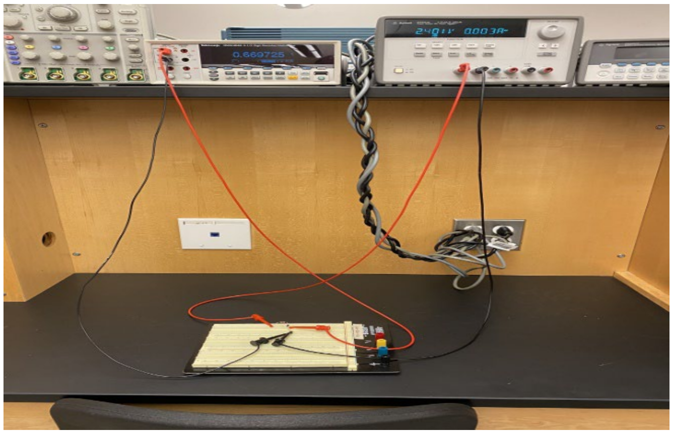

Figure 6. Diode Bias Circuit Constructed in a Traditional Lab

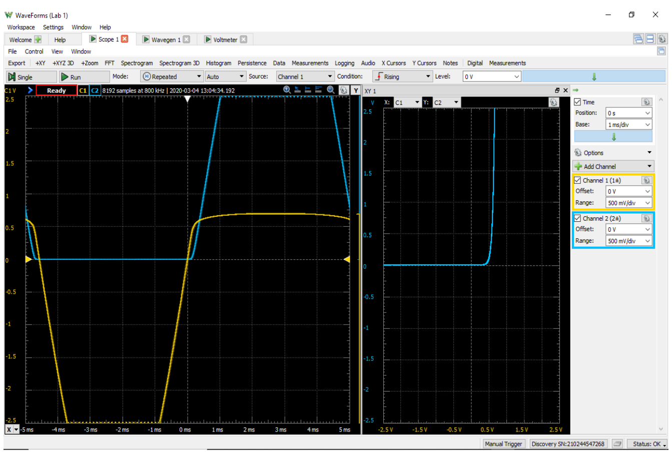

Figure 7. Plot of Diode Current I_D versus Forward Voltage Drop V_D using Analog Discovery

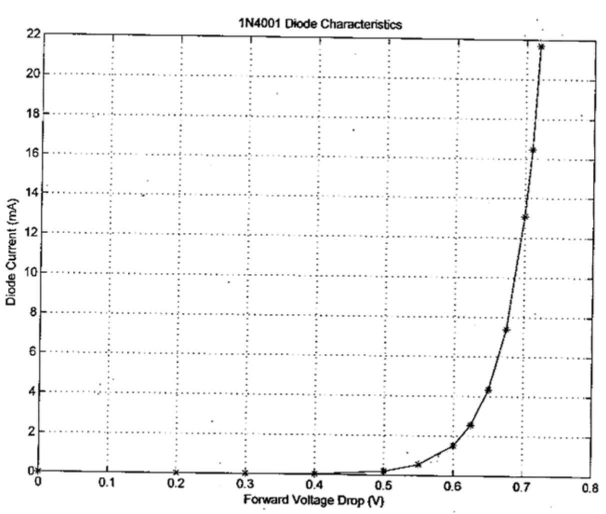

Figure 8. A Plot of Diode Current I_D versus Forward Voltage Drop V_D using MATLAB

Observation of the plot indicates the diode does not initially conduct. During the voltage range from 0 to 0.7 volts, the amperage is 0 amps. At this point, there is no current conducting through the diode. At 0.7 volts and higher, the diode begins to conduct, and the current increases linearly along with an increase in voltage; crossing the barrier potential of 0.7 volts for the silicon diode. Therefore, the objective of the lab was met with the display of the forward bias characteristics of a PN junction diode using Analog Discovery as demonstrated in Figure 7. The oscilloscope and XY plot feature were used to display these characteristics. The sample lab demonstrated the effectiveness of using the waveform generator, oscilloscope, and XY Plot feature in Analog Discovery in lieu of traditional equipment and plotting software such as MATLAB demonstrated in Figure 8.

The results prove students could gain all essential engineering skills obtained in an undergraduate program using Analog Discovery and the other virtual devices chosen in this research. Skills otherwise obtained in a traditional laboratory, for building blocks from freshmen to senior level courses.

The cost for virtual devices for the duration of an undergraduate engineering program is comparable to book costs and traditional lab fees. For this research, lab instructions were provided for the students. Purchasing lab books was not required. Not having to purchase a lab book for each course was cost effective for the students.

8. SURVEYS

Surveys were conducted to determine the effectiveness virtual labs with implemented hardware had on student learning and capabilities. The pre- and post-engineering surveys were conducted with 13 Jackson State University engineering students. The Coronavirus Disease 2019 (COVID-19) became a pandemic causing schools to close. Consequently, limiting the number of students available to participate in this research. Figure 9 displays the results of the post-engineering survey questions regarding the use of virtual hands-on hardware.

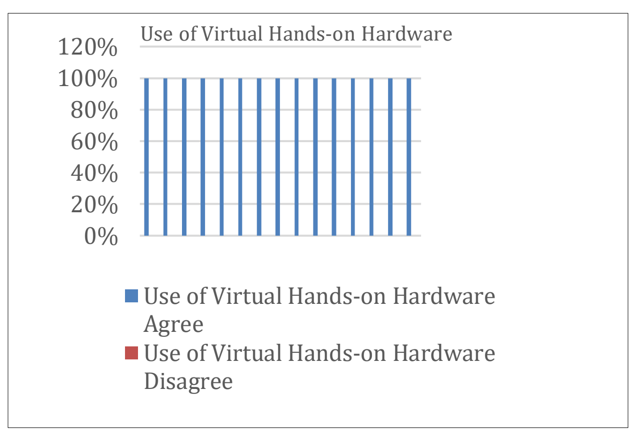

Figure 9. Post-Engineering Survey- Use of Virtual Hands-on Hardware

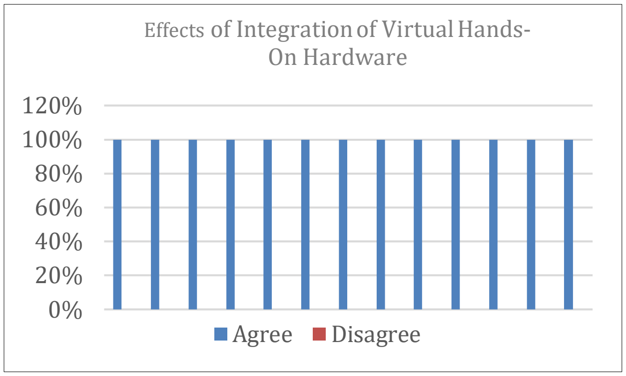

Figure 10. Post-Engineering Survey- Effects of the Integration of Virtual Hands-on Hardware

These results display the students' opinions regarding the use of virtual hands-on hardware regarding relevancy to their academic area, their knowledge increased as a result of use, and their confidence in the content area increased because of use, using the virtual hands-on hardware encouraged the students to engage in the content, the virtual hands-on hardware provided opportunities for students to practice content, the use of the virtual hands-on hardware reflected course content, the use of the virtual hands-on hardware reflected real practice, and the virtual hands-on hardware was pertinent to their preparation as an engineer. The results indicated a resounding affirmation of the use of virtual hardware in the labs with the students. Figure 10 displays the results of the post-engineering survey regarding the effects of the integration of virtual hands-on hardware.

These results display the student's opinions regarding the effects of the integration of virtual hands-on hardware and if it built confidence in areas developing confidence in the content area, considering or thinking about problems in a graphical/pictorial or practical way, applying course content to new problems, recalling course content, develop an interest in the content area, work collaboratively with fellow students, develop attitudes of self-direction and self-responsibility, develop different ways of solving problems, develop skills in problem-solving in the content area, transfer knowledge/skills to problems outside the course, become motivated to learn course content, improve grades, confidently complete lab assignments, and learn how AC and DC circuits are used in practical applications

These results indicated a resounding affirmation for each category in reference to the use of virtual hardware in the labs with the students. The students conveyed a desire to complete more labs; however, these labs were instructed through research and not a traditional lab course.

The takeaway from the overall student's perspective is the belief that increased use of virtual hands-on hardware in experiments conducted during this research enhanced learning potential.

9. CONCLUSION

Online labs in the science disciplines of STEM education have evolved increasing the interest in online labs in engineering. The flexibility virtual learning provides during the matriculation of an undergraduate degree is enticing to students and allows universities to market another category of students increasing enrollment, making this research important.

The labs conducted by the students provided the same learning outcomes as traditional labs, determined by ABET. The students conducting the labs were surveyed and the responses were favorable. The students found using the virtual devices to be easy and gained independence quickly. They were immensely receptive to conducting the experiments anywhere and welcomed the capability to practice the lab experiments outside the laboratory. Using Analog Discovery as a methodology to conduct virtual labs to circumvent the obstacles of implementing required labs for electrical and computer engineering programs was successful.

10. ACKNOWLEDGEMENT

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